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Publication date
2015/12/29
Journal
AIP Conference Proceedings
Volume 1699
Issue 1
Pages 040002
Publisher AIP Publishing
https://doi.org/10.1063/1.4938317

Description
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COMBINATION OF NATURAL FIBER *Boehmeria nivea* (RAMIE) WITH MATRIX EPOXIDE FOR BULLET PROOF VESTS BODY ARMOR

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Abstrac. Ballistic protection equipment, such as a bulletproof vest, is a soldier's most important means of preserving life and survivability in extreme combat conditions. The bulletproof vests are designed to protect the user's chest from injury without disturbing the ability to perform his duties. Aromatic polyamide or aramid fibers known under the trade name Kevlar, Trawon and so is synthetic fiber materials commonly used in the manufacture of bulletproof vests. This synthetic fibers have high tensile strength and ductility. Kevlar is expensive and imported material. In this study, will introduce local natural raw materials, ramie fiber (Boehmeria nivea) which is cheaper and environmentally friendly. It has enough tenacity and tensile strength as a bulletproof vest . This experiment uses two panels, there are Panel A as front surface of Panel B. Panel A is a combination of ramie and epoxide matrix, while panel B is only ramie.From several variations of experimental combinations between Panel A and Panel B, optimal combination obtained with 16 layers of panel A and 31-34 layers of panel B which is able to protect againts cal. 7.65 mm x 17 mm (.32 ACP) bullet fired through pistol .32 Pindad from a distance of 20 meters. Panel with a size of 20 cm x 20 cm has a total thickness between 12,922 to13,745 mm and a total weight between 506,26 to520,926gram. Scanning electron microscopy (SEM) observations indicated that the porosity and surface area of the ramie fiber is smooth, fiber surfaces showed topography with micropores. SEM also showed well-arranged structure of fibers bonding. Energy Dispersive X-ray (EDX) analysis indicated 100 % carbon contents in ramie fiber. Test result indicates that panel from composite ramie-epoxide can reach the level 1of International Standard of NIJ - 010104. Compared to panel from polyester fiber, the panel from composite ramie-epoxide (0,50-0,52 kg) is lighter weight than panel polyester fiber (1,642 kg).

Key words: bulletproof vest; epoxide; ramie (Boehmeria nivea); SEM-EDX

INTRODUCTION

Bulletproof vest is protective clothing to minimize injury because the bullet hit. This vest protects the wearer by withstand the penetration into the body. When the vest withstand penetration of bullets, the bullet impact is reduced by spread the momentum throughout the body [1]. Aromatic polyamides or aramid fiber known by the trade name Kevlar, Trawon and so is the fiber material used in the manufacture of bulletproof vests [1]. It is a synthetic fiber with high tenacity and high rigidity [1]. Tensile streght of Kevlar is ± 3.6 to 4.1 GPa [2].

So far needs a bulletproof vest in Indonesia still rely on imports, with the raw material Kevlar. Kevlar is good and strong, but the price is quite expensive [1]. In addition, the limitations of technology and human resources caused Indonesia does not yet capable to producing aramid fiber (Kevlar).

Therefore, it is needed to do some research manufacture about bulletproof vest with ramie fiber that has high tensile strength, low price and easy to get in Indonesia. Compared to the price of Kevlar Rp 140,000.00-300,000.00 per meter [3], the price of ramie fiber is cheaper. The price of ramie fibers is Rp 42000.00 per meter. Ramie fiber is a natural fiber which has advantages, more environmentally friendly because it comes from nature (biodegradable).

Earlier study, in 2009 the Center for Textile conduct research bulletproof vest with raw material of polyester fiber, the weight of the panel reached 1,642 kg. This panel was tested with a .38 Special bullet. In this study, we make bulletproof panel of ramie fiber combined with epoxy resin that tested with .32 ACP (FMJ) bullet, where speed and penetrating power of .32 ACP bullet greater than .38 Special bullet. The.32 ACP bullet has average speed V10 = 290 m/s [4]. As for the .38 Special bullet has average speed V10 = 280 m/s [5]. In addition, the .32 ACP bullet is a type of FMJ (full metal jacked) ammunition which includes hard core ammunition. The hard core ammunition is an ammunition that the bullet is made of hard materials, one of which lead wrapped with copper, as the amunition were used in this study. As for munitions in the earlier study, the .38 Special bullet is munition types of soft core, which the bullet is made of lead, without a copper sheath. The .32 ACP ammunition is used on the gun, while the .38 Special ammunition used in a revolver. To use in close combat is now more frequently used gun type weapon because it is easier in charging and capacity more than a revolver bullet [6]. FMJ bullet types with one example of the wrapping material is copper, has a better ability to withstand pressure and stress shots the rest of the barrel of a gun [7].

EXPERIMENTAL METHOD

Raw Materials

Raw materials used in this study was ramie thread and cotton-rayon thread derived from Karangploso, Malang; pure ramie cloth derived from Denpasar, Bali ;and resin epoxide derived from the market.

Experimental Procedures

Epoxide Making Procedure (Experiment I)

Mixing resin and harderner appropriate specified ratio, then stir gently until homogeneous (± 2 minutes in 200 ml mixture) in the beaker glass , then left at room temperature until dry/solid hard.

Panel Making Procedure (Experiment II)

The ramie thread combine with rayon-cotton thread woven traditionally became a cloth. The cloth cut in size of 11 cm x 11 cm. While, the epoxide resin is prepared by mixing 1 part harderner with 5 part of resin, then stirred gently until homogeneous. Epoxide resin is applied to the surface of the cloth (size 11 cm x 11 cm) until several layers. Epoxide resin functions also as an adhesive between the cloth as a glue. Combination of cloth-epoxy is pressed manually. Then left at room temperature until dry/hard.Then the panel test-fired.

Panel Making Procedure (Experiment III)

Some of pure ramie cloth size 20 cm x 20 cm glued together with epoxy resin ratio 1 harderner : 5 harderner and allowed to dry/hard durinng ± 6 hours (as a front panel/A). Prepared 50 layers of pure ramie cloth size 20 cm x 20 cm without resin epoxy (as a back panel/B). Panel A as a front surface of panel B, then the panel test-fired.

Panel Making Procedure (Experiment IV)

Prepared 16 layers of pure ramie cloth size 20 cm x 20 cm glued together with epoxy resin ratio harderner : resin (1 : 5) and allowed to dry/hard during ± 6 hours (as a front panel /A). Prepared certain number layers of pure ramie cloth size 20 cm x 20 cm without resin epoxy (as a back panel/B). Panel A as a front of the panel B, then the panel test-fired.

Experimental Analysis

Hardness analysis (Shore) of Panel Ramie-Epoxide

Hardness analysis of bulletproof panel combination with ramie fiber and epoxy resin is carried out by durometer type A (JIS K 6301). The method used is ASTM D2240 [8] [9]. In this test, several layers of cloth glued with an epoxy matrix into a panel, the bulletproof panel left at room temperature until dry. After that, tested by placing a needle durometer upright on the surface of the panel, and press slowly. Keep pressing horizontally on the surface of the panel so that the hardness can be read accurately. Using tools (Durometer) we can find out how hard the material. It works by penetrating (a needle) into the material (measuring the depth of the indentation in the material created by a power conferred on the standard presser foot), and the indicator needles measuring 0-100 °. The greater the degree ,the harder the material being measured. Unit for the measurement of hardness is "shore" [8] [10]. To material type of rubber used type A (for a tougher material such as plastic using type D). Type A durometer (JIS K 6301) is applied to the measurement of soft rubber, elastomers, printing rollers, nitriles, wax, fibrous material, silicone and polyurethane sealant [8] [10]. As for the type D durometer is used for measuring the hardness of the harder material, such as hard rubber, elastomers, hard plastic and rigid thermoplastics, and rigid epoxy based materials [8] [10]. Of existing reference, should the hardness test of panel is measured by durometer type D, due to limitations of available tools, testing is done by durometer type A. However, the results of durometer type A may be converted to the durometer type D [10], in accordance with the conversion table provided by Pecora Corporation.

Penetrating Power Analysis

Penetrating power analysis was done by a panel of ramie-epoxide shooting with .32 ACP ammunition at a distance of 20 m. Selected this distance because acording to Technical Data Sheet PT. PINDAD number JC08.00416 of .32 ACP ammunition that firing testing accuracy at a distance of 20 m.

Weight Analysis

Analysis is done by weighing bulletproof panel with digital analytic balance. Will be selected the lightest weight panel and withstand the bullets. It shall provide protection. Selected the lightest panel because one of the requirements of bulletproof vests is it should be light weight, comfortable to use and providing optimum mobility and speed [11].

Thickness Analysis

Analysis is done by measuring the thick bullet-proof panel with digital vernier calipers. On this analysis did not selected the smallest thickness, but only to knew thickness of the optimal bulletproof panel (the lightest weight).

SEM-EDX Analysis

Analysis SEM (scanning electron microscopy) -EDX (energy dispersive x-ray) is performed with a zoom in 1000, 1500 and 2000 times. Scanning Electron Microscopy (SEM) is a tool used to observe small specimens. How to get a microstructure with reading the electron beam, the electron beam in the SEM in the form of small stains which are generally 1μm on the surface of the specimen observed repeatedly. The surface of the specimen was photographed and analyzed the existing condition of this specimen or damage of the specimen [12]. SEM is the importance of giving a real picture of a small section of the specimen, which means we can analyze fiber size, bonding and roughness.

RESULT

Experiment I

Selected mixing ratio of harderner : resin are 1:1 to 1:30 because at some references mixing ratio epoxy resin is in the range of 1:3 [13], 1:5 [14] or can be any depending on needs, up to more than 1:10 [15]. The process of polymerization/curing time can be influenced by the ratio of resin and hardener [16], so the experiment was carried out mixing resin and harderner with various ratios aim to see the effect of the ratio of resin : harderner against polymerization process/curing time.

TABLE 1. Variation mixture ratio of harderner and resin

Ratio harderner : resin	Curing time	Note
1 : 30	> 22 days	No exotermic reaction and No harderner oddor
1 : 25	> 10 days	No exotermic reaction and No harderner oddor
1 : 20	> 10 days	No exotermic reaction and No harderner oddor
1 : 18	± 7 days	No exotermic reaction and No harderner oddor
1 : 15	± 6 days	No exotermic reaction and No harderner oddor
1 : 10	± 4 days	No exotermic reaction and No harderner oddor
1 : 5	± 6 hours	Any exotermic reaction (warm) and Harderner oddor not too much
1 : 3	± 6 hours	Any exotermic reaction (hot) and excess harderner oddor
1 : 1	> 66 days	Any exotermic reaction (hot) and excess harderner oddor

The experimental results (Table 1) shown a phenomenon that the greater the harderner added, the shorter curing time happen. Except at a ratio of resin: harderner is 1:1. On the ratio 1 resin : 1 harderner, it was instead the longer curing time (more than 66 days). On the 66^{th} day, the mixture of resin and harderner change from a liquid into a kind of paste that elastic (when the surface was pressed, then back to shape before). This stage is actually happening at all ratios. A mixture of resin and harderner which is in liquid form, after stirring and allowed at room temperature turn into a paste form that elastic. Then it eventually become very hard, it's just time to turn into a different hard solid.

Table 1 shown the optimal ratio of harderner : resin is 1 : 5. The optimal ratio means short curing time, low heat of exothermic reaction and no ammonia oddor from harderner. Viewed curing time in Table 1, for ratio harderner : resin are 1 : 1 or > 1 :

10 curing time is too long (> 1 day). The longer curing time is inefficient as it would require a high operating cost (when applied to the production scale, the machine's time and operator's time will be increase and production capacity become lower due to make one product takes a long time).

The curing time of 1 harderner : 3 resin as same as the curing time of 1 harderner : 5 resin. In further experiments will be used ratio of 1 harderner : 5 resin because of the smell of ammonia from harderner lesser than ratio of 1 harderner : 3 resin.

Experiment II

TABLE 2. Result of experiment II

Number	Ratio Harderner : Resin	Number of layers	Thick (mm)	Weight (gr)	Penetration	Hardness* (measured after 3,5 weeks)
1	1 : 5	20	13,12	130,2	**Fired Through**	100
2	1 : 5	23	13,66	135,1	**Fired Through**	100
3	1 : 5	26	14,95	138,9	**Fired Through**	100
4	1 : 5	29	15,28	146,6	**Fired Through**	100
5	1 : 5	32	19,71	204,1	**Fired Through**	100
6	1 : 5	35	21,68	228,4	**Fired Through**	100
7	1 : 5	38	22,92	239,7	**Fired Through**	100
8	1 : 5	41	24,61	269,9	**Fired Through**	100
9	1 : 5	44	25,25	270,5	**Fired Through**	100
10	1 : 5	47	26,61	276,0	**Fired Through**	100
11	1 : 5	50	30,53	311,0	**Fired Through**	100

*Measured by Durometer type A (JIS K 6301)

Table 2 shown all the variation panel was pierced by bullet (firing test after 3.5 weeks drying panel). This is caused by the epoxide resin make fiber cloth becomes brittle. Cloth fibers fused with epoxide resin becomes hard, then the elastic properties (tensile strength) of fiber is lost, so that the panel could not withstand a bullet although at ± 3 cm thick.

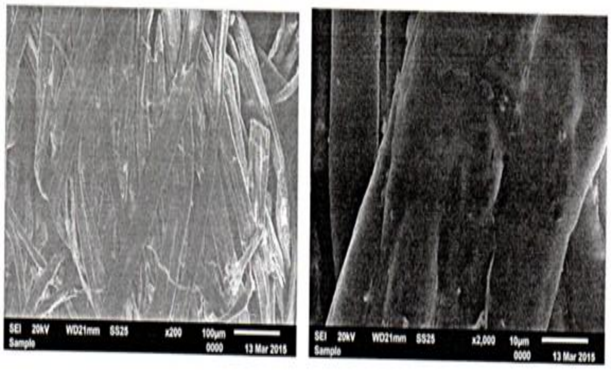

FIGURE 1. SEM (*scanning electron microscopy)* Analysis of ramie-rayon-cotton cloth

SEM analysis (Fig. 1) shown the fibers that woven traditionally has irregular fiber structure, untightly bonding fibers, and roughtly surface. The pores surface are not uniform (large and small). Those mechanical properties will degrade the performance of fiber (easily broken).

EDX test results shown the fiber cloth containing 99.69% Carbon and 0.31% Aluminum. This happens because the cloth does not come from pure ramie thread, but woven from cotton thread and ramie-rayon thread. Carbon derived from cotton and ramie itself because the chemical composition of ramie and cotton consist a lot of cellulose [17] [18] [19] [20]. The content of cellulose is one of the criteria that indicate the strength of the fiber. Excellent mechanical properties of the cellulose are strain, strength, resistance to pressure, it also expands and increases permeability properties during the process of forming the wall [21]

However, the application of this cloth in experiment II was not able to withstand bullets because all the layers of cloth that combine with an epoxide resin became hard and brittle. In the second experiment, panel with a thickness of 3.053 cm (Table 2) was pierced by a bullet.

Experiment III

TABLE 3. Date of panel after firing

Panel A (layer)	Panel B (layer)	Total weight (gr)	Total thick (mm)	Withstand in panel B (layer)	
				Firing-1	Firing-2
10	50	472	14,83	pierced	pierced
12	50	491	15,79	pierced	pierced
14	50	534,82	16,75	41	42
16	50	565,1	16,98	34	33
18	50	616,7	17,83	27	30

Table 3 shown that the combination panel with has number of panel A 10 and 12 layers still cannot withstand the bullets, while in combination panel with number of panel A 14, 16, and 18 layers can withstand the bullet. Each panel combination shot two times by .32 ACP ammonitions. Combination of panel A and B were not penetrated bullets, it can be analyzed its weight and thick.

Results of firing shown munitions successfully nested on the panel and do not penetrate the panel B (Fig. 2). When the panels withstand the bullets, the bullet's impact is reduced by spread the momentum throughout the body [1]. Users will still feel the kinetic energy of the bullet, it can cause bruising or hurting seriously. The combination of panel A and panel B succesfully withstand the bullets because of the energy and speed of bullet has been reduced a lot when it hit panel A, then residual energy and speed of the bullet withstand by panel B that consist of 100% ramie cloth, where ramie has high tensile strength. Ramie has high tensile strength that able to withstand the pressure residual of kinetic energy of bullets. When bullet hit the panel B, fiber of ramie cloth is stretching and absorbing energy and spreading the pressure to all vest surface, so that energy is not enough anymore to make bullets fired throught a vest [22].

The strength of ramie fiber derived from cellulose as a major constituent of ramie fiber . Cellulose has the formula (C_6 H_{10} O_5 $)_n$, where " n " is the degree of polymerization and most of the ramie fiber consists of ± 75 % cellulose. Analysis Frenderberg, Haworth and Braun in the book Textile Fiber indicating that cellulose is formed by a ring of glucose, so it can be mentioned that the structure of cellulose fibers is the unity of anhydro glucose connected to one another by oxygen bounds in position 1-4 [20]. In plant, cellulose molecules are arranged in the form of fibrils composed of several parallel molecules linked by glycosidic bonds so it is difficult to be outlined [23] [24]. The chemical composition and structure thus makes most materials containing cellulose is strong and hard [23].

EDX analysis of pure ramie fiber shown ramie fiber containing 100 % carbon that came from carbon chains to form cellulose. Cellulose is never found in nature in a pure state, but always associated with other polysaccharides such as lignin, pectin, hemicellulose, and xylan [23]. Most composition of ramie consists of cellulose that is an organic material which has a chemical structure consisting of carbon [17-20]. Cellulose is one of the criteria that indicate the strength of the fiber [21]. Most cellulose associated with lignin so often referred to as lignocellulose. Cellulose, hemicellulose and lignin produced from photosynthesis. Cellulose is a structural polysaccharide that serves to provide protection, shape, and a buffer to the cells and tissues [21]. Naturally molecules are arranged in the form of cellulose fibrils which consist of several cellulose molecules connected by glycosidic bonds. These fibrils form a crystalline structure which is covered by lignin. The chemical composition and structure thus makes most materials containing cellulose is strong and hard. Strong and hard nature possessed by most of the cellulose material that makes the material resistant to enzymatic decomposition. Naturally cellulose decomposition takes place very slowly [23]. The content of cellulose and lignin is one of the criteria that indicate the strength of the fiber. Excellent mechanical properties of the cellulose are strain, strength, resistance to pressure, it expands and increases permeability properties continue during the process of forming the wall [21].

In addition, SEM analysis (Fig. 3) shown that the image of pure ramie fiber that woven by machine are more regularly structure, tightly bounded fibers and the fiber's surface looks smoother (mikroporous), so it is not easily broken when hit by pressure. So it give good performance of pure ramie cloth that able to withstand the pressure of the bullet on the experiment III (Table 3).

FIGURE 2. Panel B withstand the bullets

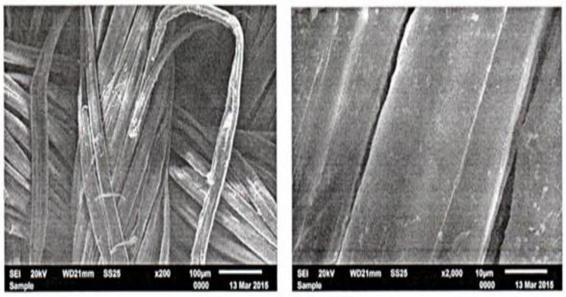

FIGURE 3. SEM (*scanning electron microscopy)* Analysis of pure ramie cloth

At the experiment III, the pure ramie cloth able to withstand bullets because use two panels, A and B. Panel A is composed of ramie cloth combined with an epoxy resin, which makes the fiber became brittle, so that the panel A can not withstand the bullet. But when bullet fired throught the panel A, the kinetic energy of bullet is already reduced, and the residual kinetic energy of bullet withstand by panel B. Panel B that consist of layers of pure ramie thread that woven by machine able to withstand bullet, if it combined with panel A 16 layers as front panel.

In the experiment II, panel which 3.053 cm (Table 2) total thicness pierced by bullet. Compared to experiment III which has a total thickness of the panel 1,675-1.783 cm (Table 3), it can withstand the bullet. This proves that the existence of panel B that consist of a pure ramie cloth that has a high tensile streght give significant effect.

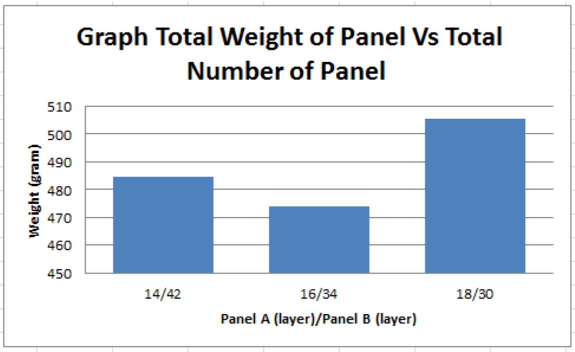

FIGURE 4. Graph total weight vs total number of panel

From the graph (Fig. 4) shows that the combination of panel A 16 layers and panel B 34 layers have lighter weight than another panel combinations.

Experiment IV

Data from Table 4 shown that the variation of panel B does not give significant effect to ability of panel. All combination panel in Table 4 withstand the bullets in panel B 31-34 layers.

TABLE 4. Result of firing

Firing	Panel A (layer)	Panel B (layer)	Withstand in panel B		
			Number of layers	Weight (gr)	Thick (mm)
1	16	40	31	160,91	6,50
2	16	45	33	174,765	6,81
3	16	50	32	170,05	6,57
4	16	55	31	163,73	6,217
5	16	60	34	175,576	7,04

TABLE 5. Date of each firing

Firing	Weight (gram)			Thick (mm)		
	Panel A	Panel B	Total	Panel A	Panel B	Total
1	345,35	160,91	506,26	6,705	6,50	13,205
2	345,35	174,765	520,115	6,705	6,81	13,515
3	345,35	170,05	515,4	6,705	6,57	13,275
4	345,35	163,73	509,08	6,705	6,217	12,922
5	345,35	175,576	520,926	6,705	7,04	13,745

The data above shown that the optimal combination of panel is panel A 16 layers and panel B 31-34 layers, which total weigh is 506.26 to 520.926 grams and thickness between 12.922 to 13.745 mm. Data weight and thickness is per 20 cm x 20 cm = 400 cm2.

The panel can withstand .32 ACP bullet that according to International standart NIJ 101004 (Table 6), this panel include the level I [2].

TABLE 6. Standart International NIJ 101004

Level	Type of bullet	Weight of Bullet (gr)	Impact of Velocity (m/s)
I	.22 cal LR, LRN	2,6	329
	.380 ACP, FMJ RN	6,2	322
IIA	9 mm, FMJ RN	8	341
	.40 S&W FMJ	11,7	322
II	9 mm, FMJ RN	8	367
	0.357 Mag JSP	10,2	436
IIIA	9 mm, FMJ RN	8,2	436
	.44 Mag SJHP	15,6	436
III	7,62 mm NATO FMJ	9,6	847
IV	.30 cal M2AP	10,8	878

Note :
AP = Armor Piercing
FMJ = Full Metal Jacked
JSP = Jacked Soft Point
LRHV = Long Rifle High Velocity
RN = Round Nose
SJHP = Semi-Jacketed Hollow Point
SWC= Semi-wadcutter

ACKNOWLEDGMENTS

Woven ramie can be developed as a bulletproof vest. It has been tested and withstand bullets of 7.65 x 17 mm caliber (.32 ACP) Full Metal Jacket at a distance of 20 m. The ratio of harderner : resin optimal (short curing time, the exothermic heat and the smell is not too strong) is 1 : 5. Ramie cloth layers are glued together with epoxy resin is not able to produce bulletproff panels.The optimum number of panel A is 16 layers. Variations in the number of layers of panel B does not give significant influence on the strength of the panel. Optimal combination of panel consist of 16 layers panel A and 31-34 layers panel B, which total weigh is 506.26 to 520.926 grams per 400 cm². Test result indicates that panel from composite ramie-epoxide can reach the level I of International Standard of NIJ – 010104.

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